Mechanical Filtration for Municipal Water Supply

R. S. Spalding

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MECHANICAL FILTRATION

for

MUNICIPAL WATER SUPPLY

By Roy S. Spalding.

.....

A Graduation Thesis Presented to the Faculty

of

ARMOUR INSTITUTE of TECHNOLOGY

For the Degree of B. S.

In Civil Engineering.

.....

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C O N T E N T S.

I

Introductory Page 1

II

Mechanical Filtration Page 6

III

Design of Mechanical Filtration Plant Page 13

IV

Operation of Plant Page 22

V

Conclusions Page 25

Bibliography Page 27

Plates

PREFACE

While endeavoring to decide upon a suitable subject for my graduation thesis I was impressed with the great importance of a sufficient supply of pure, wholesome water to the health and happiness of any community. I was also impressed with the fact that some of our largest cities, as well as many smaller ones, are being supplied with polluted lake or river water, which has often spread disease and death, by means of deadly disease germs which it carried.

That something must be done to change such a condition of affairs is very evident. It would be impossible in all cases to change the source of supply and, therefore, I believe that filtration will play a great part in supplying our cities with pure water in the future.

I have endeavored in this thesis to describe in a general way the process of filtration, to show the need for it, and some of its advantages, and to describe in detail the general design of a plant which I have prepared.

I desire to acknowledge my indebtedness to Mrs. Beveridge and her assistants in the Library, who aided me greatly by kindly preparing a bibliography containing a complete list of books and articles on filtration. I wish also to express my appreciation of the kind assistance of Prof. Phillips.

ROY S. SPALDING.

I

INTRODUCTORY.

A recent and important feature of hydraulic engineering in this country is the growth of the practice of filtering public water supplies. Formerly filtration was looked upon with general disfavor, chiefly because of a mistaken idea of its powers of purification. A few years ago it was necessary to depend upon chemical analyses for information regarding the purity of a water supply. But with the development of the science of bacteriology a higher standard was set, and it was determined that filtration was very efficient in removing bacteria, usually reducing the number by 98 per cent. or over. It has also been shown upon good authority that, contrary to previous belief, filtration has a marked chemical effect upon the water.

Another reason for the growing interest in filtration is the contamination to water supplies that were once pure, caused by an increase in population, and the practice of discharging waste from manufacturing establishments into rivers and lakes. Under such circumstances it is often difficult to obtain a pure supply of water in any other way than by filtration.

American water supplies are noted for their great volume, but are very often of such a quality as to greatly endanger the health of the people. Many of the largest American cities are supplying their people with water which, to say the least, is of doubtful purity. It is an acknowledged fact that many severe epidemics of disease, especially typhoid fever, have been caused by polluted water. Undoubtedly many such epidemics have been attributed to other causes when they have, in reality, been the results of an impure water supply.

Chicago has always suffered more or less from typhoid fever, but it is quite clearly shown by the reports of the Health Commissioner that the typhoid fever death rate has fluctuated with the degree of pollution of the lake water. In 1892 the old intake, near the mouth of the Chicago River, was abandoned, and this resulted the year following in a decrease of 60 per cent in the typhoid fever death rate. Such results as this show conclusively the effect that the quality of the public water supply has upon the general health of a community, and demonstrate the necessity for purification.

The practice of European cities in regard to filtration is worthy of notice here. The first filters

constructed for the filtering of a municipal water supply were built at London, in 1839, by James Simpson. He built them for the Chelsea Water Company. They were expected simply to clarify the water, little being known at that date as to the powers of purification of properly designed filters. What is known as the English method of filtration has been usel in more water works systems, both in Europe and America, than any other. It may be otherwise called the method of slow sand filtration, being slow, when compared with the American system of rapid sand filters. The water is applied to a bed of sand two and one-half to five feet deep, and filters through this at a a rate of one and one-half to five million gallons per acre per day. Many places in England are at present being supplied with filtered water.

In Germany of late years many millions of dollars have been spent for the installation of filter plants to purify the polluted river waters. In 1892 the City of Hamburg, Germany, learned a very costly lesson when, in the course of one month, eight thousand people died of an epidemic caused by an unwholesome, polluted water supply. Hamburg profited by the epidemic and now has a new and pure supply of filtered water.

France and Austria have also used filtration successfully, although not as extensively as either Germany or England.

There are three essential means of obtaining a good supply of pure water, as described by Hazen in his book, "The Filtration of Public Water Supplies." The first method consists of damming a stream from a sparsely settled water shed. This method is much used in Europe, in California, and in many portions of the United States, and is especially desirable in mountainous regions, and where a suitable water shed is within a reasonable distance. It is not useful to any extent in low, fertile countries, as the states of the middle West, like Iowa and Illinois, which are sure to become densely populated.

The second method mentioned is to secure ground water from wells and springs. This method is perhaps the earliest and most widely used of any, but it is only useful for small supplies, unless unusual geological conditions prevail, such as in Europe. There large supplies are found, and such cities as Paris, Vienna, Budapest, Munich, Cologne, Leipzig, Deesden and a part of London are so supplied. In the United States geological conditions limit the use of ground

water to the smaller towns, but it is used extensively for such places. Ground water may be said to be the product of Nature's own filters, and is certainly a splendid supply when obtainable.

The other method is the one under discussion, viz:, the filtration of surface water, which would otherwise not be fit for domestic use. Filtration is no longer an experiment. It has passed that stage, and is now an established fact. Hazen estimates that European cities, with an aggregate population of at least twenty million people, are at present supplied with filtered water. In the United States it has not attained these proportions, but much has been done in late years toward furnishing the people with water of unquestionable quality, as well as large quantity.

II

MECHANICAL FILTRATION.

The objects of filtration, or any method of purification, may be said to be four-fold, depending upon the condition of the water to be treated, namely, to remove bacteria; matter in suspension; matter in solution, and color. There are many methods of purification by which these objects have been accomplished, which are in general, as follows: Sedimentation; mechanical filtration, with or without the use of coagulants; slow sand filtration, in which the organic matter is oxidized, usually known as the English method; chemical purification, which includes the softening of hard water, and removing iron in solution by aeration; and distillation.

It is evident that a method of purification which is adapted to one water might not be at all suitable to another. For instance: mechanical filtration gave excellent results at Wilkesbarre, Pennsylvania, but

was a failure at New Orleans; and slow sand filters have proved useless for some of our muddy streams, while entirely successful at some other places.

Sedimentation is useful principally to remove heavy matters in suspension. A good example of this method is a series of five basins, each a little lower than the one before it, which are in successful operation at Omaha, Nebraska. The water of the Missouri River, which is used there, and which is very heavy with clay, is rendered clear and wholesome by its slow passage through the basins. This method is very economically used in conjunction with filtration, as will be seen later.

There are many types of mechanical filters in use in the United States, to filter water for manufacturing and domestic use, which consist generally of an iron cylinder, filled with sand, through which the water is forced by pressure or by gravity, at the rate of from one to three hundred million gallons per acre per day. These different types of filters, of which there are many patented kinds upon the market, differ from each other mainly in the mechanical means of agitating the sand when washing the filter. In such filters it is not possible to clean them by scraping the sand surface,

as in slow sand filters, but the whole body of the sand must be stirred up and thoroughly washed. It should be thoroughly understood at this point that, as far as purification is concerned, all methods of filtration, whether slow or rapid, with or without coagulants, and in all types of filters, are essentially the same in principle.

Some splendid examples of rapid sand filters, combining sedimentation with filtration and the use of alum as a coagulant, and operated by gravity, have been constructed at Youngstown, Ohio, and at Anderson, Indiana.

The use of a coagulant, usually sulphate of alumina, or alum, very greatly facilitates both sedimentation and filtration. The alum, which is added in small quantities, is decomposed into its component parts, sulphuric acid and alumina. The sulphuric acid combines with the lime, or other basic substance, in the water, while the alumina forms a gelatinous precipitate, which draws together, or coagulates, the suspended matter and bacteria in the water, and allows them to be more easily removed by the filters. In addition to this, the alumina has some sort of a chemical affinity for organic matters in solution, and is, therefore, useful in removing turbidity, which would be impossible

without the aid of the coagulant.

The use of alum is not a new idea. As early as 1831 it was used in the purification of Nile River water in Egypt, which was afterward filtered in small household filters. There have been some objections to its use, which should be considered. When used indiscriminately in any and all kinds of water it would certainly be dangerous. If there is not enough lime, or other base in the water to neutralize the acid set free, this acid will act on the iron pipes of the distribution system, and the water will be liable to contain a trace of iron, giving it a disagreeable taste, and a bad color. This very condition of affairs occurred in Antwerp in 1893, and caused the water company there considerable trouble. The objection that the alum is injurious to health is hardly worth considering, on account of the extremely small proportion of alum used, and on account of the fact that there are hundreds of small filter plants in operation in small cities and towns where the charge of chemicals is not very carefully watched, and yet without a single instance being recorded of injury to the health of the community.

However, care should be exercised that the quantity of alum used should not be greater than will

correspond to the alkalinity of the water, which would render the water acid and dangerous, as shown above. Also, that the amount of alum should not be too small, which would tend to reduce the efficiency of the filter in removing bacteria, turbidity and color. The quantity of alum will depend, therefore, upon the condition of the water and the results desired.

In the Providence experiments 0.6 grain per gallon was found sufficient, while at Cincinnati it was found necessary to use about 1.6 grains per gallon. Practice differs considerably as to the time of applying the alum solution to the water, depending upon the work expected of the coagulant. If the alum is expected to help in the sedimentation it should, of course, be added before the water enters the sedimentation basin. On the other hand, if the matter in suspension is of such nature that it will settle out of its own accord in the course of a few hours, it would be unnecessary to add the alum before sedimentation, and if the matter in suspension is clay, it would be a waste of chemical, as it has been shown by Mr. Fuller in his Louisville experiments, that clay particles have some faculty of absorbing and holding the sulphate of alumina, so that a larger quantity of the chemical may be taken up by the

water than its alkalinity will account for.

After a filter has been in use a short time it will begin to clog up, thus increasing the head necessary to give the desired flow through the filter. As this head increases it reaches a limit at which the filter can be economically used, and the filter must be shut down and washed. This allowed loss of head is usually about eight feet. The filter is washed by stirring up the sand by some mechanical means, or by compressed air, and then forcing the wash water back through the effluent pipes, through the sand and out through the influent pipes to the sewer. This washing removes the dirty gelatinous coating on the sand grains, opens up the sand, and decreases the necessary head required to force the water through.

After washing the filter, it has been observed that the bacterial efficiency is slightly decreased, owing to the removal of the gelatinous film which aids in removing bacteria. This condition only lasts for a short period of time, but on this account it has been the practice to waste the effluent for a time after washing. Mr. Fuller advisesthat this is unnecessary, as the effect of this reduction in efficiency would not be sufficient in a plant containing several units to

to cause any harm. Mr. Weston found at Providence that after filters have been used for several months, washing will not restore them, so he advised that after six months they be washed out with caustic soda.

From the preceding discussion we must conclude that the amount of coagulant applied, the rate of filtration, and the frequency of cleaning will all depend upon local conditions.

III

THE DESIGN OF A MECHANICAL FILTRATION PLANT.

In beginning the design of a filter plant, such as has been briefly described, we will start with the assumption that we have to purify a supply of five million gallons per day. This supply would be about sufficient for a town of 50,000 population. To serve the present purpose, assumptions will also have to be made regarding the character of the water to be filtered. Therefore, we will assume that the water contains such an amount of suspended matter as will render it advisable to employ three or four hours of sedimentation prior to filtration.

To provide for four hours sedimentation we would need basins with a capacity of one-sixth of the total daily supply of five million gallons, or about 834,000 gallons, which is equal to 111,497 cubic feet of volume. The dimensions of the basins which will fulfill these conditions are 48 feet by 20 feet deep. Two sections of these basins are shown on Plate 2, and

a plan is shown on Plate 1. They are to be built with walls of concrete and heavy cement bottoms. The walls are three feet thick at the top and eight feet thick at the bottom, with a footing course one foot wide, on both sides of the wall, and one foot deep, and extending all around the wall. The basins are divided by a concrete wall four feet wide at the top, eight feet at the bottom, and having the same footing course as the side walls. The floors of the sedimentation basins are reinforced with expanded metal.

Each sedimentation basin is partially divided by three vertical baffle walls, as shown on Plates 1 & 2, which insures a complete utilization of the entire capacity of the basin. These walls are made one foot thick at the top, two feet thick at the base, and are supplied with the same footing course as the other walls. These baffle walls are reinforced with one-half inch rods, on both sides of the wall, spaced on ten inch centers, and about two inches from the surface.

The inlet to the basin is through a 36 X 48 inch, horizontal, wooden trough, twenty feet long, which sets on iron brackets built into the concrete wall of the basin, twelve feet from the bottom of the basin.

Cracks are left between the planks in the bottom and side of the trough, to distribute the flow of the water. The outlet from each basin is over a weir twenty-two feet long, formed by a one-quarter inch steel plate, bolted to the wall next to the filters. The water discharges over this weir into a 30 X 30 inch flume, which is connected to the raw water feed pipe in the pipe gallery by a thirty inch tee connection.

In one corner of each basin there is a twelve inch connection to the sewer, for the purpose of draining and cleaning the basin. It is supplied with a gate valve, allowing it to be shut off. Allowing a rate of filtration of one hundred million gallons per acre per day, we would have a necessary filter area of one-twentieth of an acre, or two thousand, one hundred seventy-eight square feet. Using eight filters, each, with a sand surface of 14 X 20 feet, we would have a total filter area of two thousand, two hundred forty square feet.

Each filter tank is built entirely of concrete, as shown on Plate No.3, and the walls of each tank are built separate from the walls of the adjacent tanks, and from the walls of the building and pipe gallery adjoining. This is done as a precaution against

possible injury to the filters, which might be caused by the settlement of the building walls.

The filter tank is eight feet deep, and has a twelve inch ledge extending on three sides of it, and four feet below the top. A quarter inch steel plate is bolted vertically at the outer edge of this ledge, thus forming a 12 X 15 inch gutter on the sides of the bed. At the center of the gutter, on the end nearest the pipe gallery, there is a twelve inch connection to the thirty inch raw water main from the sedimentation basins. The raw water enters through this opening, and is distributed over the filter bed by means of the trough, the top of the steel plate being level enough to form weirs.

The filtering material is fine sand, preferably that consisting of hard quartz grains, of sizes ranging from 0.013 to 0.04 inch. Such sand is obtained from the sea shore and from river beds. The sand layer in the filter bed is three feet thick, and is underlaid by nine inches of fine, clean gravel.

The effluent manifold is a ten inch cast iron pipe, laid lengthwise of the filter tank, and embedded in the concrete floor. One and one-half inch iron collector pipes are cross connected to this at intervals

of six inches, and extend back to the walls of the tank on each side. These collector pipes are also embedded in the concrete floor of the tank, and are supplied with strainers, made according to the Deutsch patents. These strainers are small brass cylinders, perforated with fine holes, and are spaced on the collector pipes on six inch centers. This makes a total of 1120 strainers in each filter bed. At the side of the effluent manifold, and connected to it, is a four inch pipe supplying compressed air to the filter to agitate the sand when washing.

The pipe gallery which lies between the rows of filter units and carries the pipe which supplies them, is shown in detail on Plate 3. It is nine and one-half feet wide, and fourteen feet deep, and is covered over by a concrete floor six inches thick, reinforced with expanded metal and supported by nine inch I beams, set on thirty-six inch centers, and having their ends embedded in the wall of the gallery. This floor or walk is at the same level as the tops of the walls dividing the filter beds, and connects with a walk on top of the dividing wall between the sedimentation basins. The operation of the valves controlling the filters is carried on from this floor. The bottom floor of the

pipe gallery is made of concrete, and is fourteen feet below the top walk.

The thirty inch raw water main, which takes the water from the sedimentation basins and distributes it to the filters, is suspended from the I beams in the top of the gallery, and is cross connected to each filter by a twelve inch branch. Below this is supported the ten inch wash water pipe, which is also cross connected to the effluent manifold of each filter, so that water may be supplied for washing. Just above this wash water main is a four inch compressed air pipe.

Beneath the floor of pipe gallery is placed the thirty inch clear water main leading to the clear water well, and a twelve inch sewer to carry off waste and wash water. The connection to the trough of the filter bed is supplied with a three way branch, one side being the connection to the raw water main, while the other is the branch to the sewer. It is through this sewer branch that the waste water is carried off. The effluent manifold also divides in a three way branch, one branch being the supply from the wash water pipe, while the other is the connection to the clear water main.

On this branch from the effluent manifold to the clear water main is placed the controller, and connection is made to a ten inch float tube. The controller is shown in detail on Plate 4. It is a steel tank five feet long, two feet wide, and two and one-half feet deep. The water enters through a double seated balanced valve, which controls the rate of flow of the filtered water. The stem of this valve is connected to a lever arm, the other end of which is attached to a float resting on the water in the tank. As the level of the water raises the float raises and the valve is closed. The water leaves the tank by means of a standard orifice in the bottom of the tank, which is operated by the head of water in the tank. This orifice has a free discharge into air, discharging into a twelve inch pipe connecting with the clear water main. The rate at which water is passing through the filters is determined by the head on the standard orifice, and can be changed by varying the height at which the float is set. Transverse baffles in the tank prevent the rush of water through the valve from disturbing the float.

The alum solution is mixed in two concrete

tanks six feet in diameter, and eight feet deep, and applied to the water in the pump well. The solution flows from the tanks to the regulating box, shown on Plate 4, and from this box through an orifice in the bottom to the water in the well.

The filter beds and sedimentation basin are roofed over by means of a steel roof system, supported upon brick walls, built upon the top of the side walls, and forming a tee shaped building. The walls of the building should be well supplied with windows, as plenty of light is a great aid to purification of water.

The raw and clear water wells are built entirely of concrete, and the clear water well is roofed over to prevent the formation of ice in the winter time. The raw water well is ten feet internal diameter, and twenty feet deep, and is built under the floor of the pump house. The intake tunnel carries the water to the well, and from there it is pumped to the sedimentation basins. The clear water well is a separate structure by itself, having a capacity of 500,000 gallons, and being sixty-five and one-half feet internal diameter, and twenty feet deep. The walls of the basin are three

feet wide at the top, and eight feet wide at the bottom. The floor is reinforced with expanded metal, and the roof is formed by steel trusses, riveted at the center to a sixteen inch steel cylinder, set vertically in the center of the basin.

It is not the purpose here to enter into a discussion of the relative merits of different makes of pumps, but simply to state the number and capacity of the pumps required. In the first place, we will need two, five million gallon, low service pumps, with their suction in the raw water well, to pump the water to the sedimentation basins. It will be necessary to use a three million gallon pump to supply the wash water. This pump should have its suction in the clear water well. An air compressor will supply the compressed air for agitating the sand in the filters. Then, there should be two, five million gallon, high pressure pumps, with their suction in the clear water well, and pumping the water to the distribution system.

IV

OPERATION OF PLANT.

The operation of the plant should be in charge of competent and reliable men, as it is important that it have constant attention as to the amount of the chemical applied and the rate of filtration. Also the matter of washing the filters and putting them back in commission after the washing must be closely watched.

The water is taken from the raw water well by the low service pumps, and delivered through a thirty inch pipe to the inlet of the sedimentation basin. The flow of the water at this inlet is controlled by a twenty-four inch valve on the cross connection to the thirty inch pipe. After passing slowly through the sedimentation basins the water discharges over the weir into a flume connected to the thirty inch raw water main in the pipe gallery. A thirty inch valve on each side regulates the flow from the basin.

The water is distributed to the filters by the thirty inch raw water main, and, after filtering through the same, is collected by the collector pipes and strainers, and is then carried from the filter by the

effluent manifold to the clear water main, and thence to the clear water well. From there it is pumped to the distribution system.

The controllers need to be watched, because they control the rate of filtration. Also the float tube needs attention, as it shows the loss of head over the filter, and indicates when washing is necessary.

To wash a filter bed, the valve on the twelve inch supply pipe is shut down, and after the water is drawn down to a few inches below the top of the trough, a valve on the effluent pipe is closed, and the water over the bed held at that level. The valve on the twelve inch pipe to the sewer is opened, and then the valve on the ten inch wash water supply is opened, thus allowing the wash water to be forced up through the filters into the trough and out to the sewer. The compressed air should be turned on at the same time, so as to stir up the sand, and insure thorough washing. When the washing has been finished the wash water is shut off and after the dirty water in the trough has been drawn out, the sewer connection is also shut off. Raw water is again admitted, and the first water passing the filter is wasted until the effluent is clear through a

four inch by-pass, connecting the effluent pipe with the sewer. When this is accomplished the tank is again ready for service.

With competent supervision, and careful attention, such a plant will doubtless perform the work required of it, with a high degree of efficiency.

V

C O N C L U S I O N S.

An essential condition for safe operation of a mechanical filter is that the proper quantity of coagulent be continuously applied, and that care be taken that too large a quantity is not used.

We might also mention that attention should be paid to frequent cleaning of the sedimentation basins. Extreme cleanliness in all parts of the plant is very important.

Bacterial and chemical tests should be made systematically, and would serve to show the efficiency of the plant as a whole. Such tests may be made to show the efficiency of the separate filters, the efficiency at different times, the effect of cold weather, and will aid the superintendent in securing good effluents at minimum cost.

It is difficult to estimate the cost of such a plant in a general way, as local conditions have a great influence on the cost. It is roughly estimated by Hazen that the cost of filtration, with all necessary interest and sinking funds, will add about ten per cent.

to the average cost of water, as ordinarily supplied. This surely is not excessive, and places pure water within the reach of every community.

It is to be hoped that when the people of American cities realize the facts in regard to their water supplies, and see the possibilities in filtration, they will abandon the unhealthy habit of drinking polluted lake and river waters, and will place the quality of our water supply upon a level unexcelled by that of any country.

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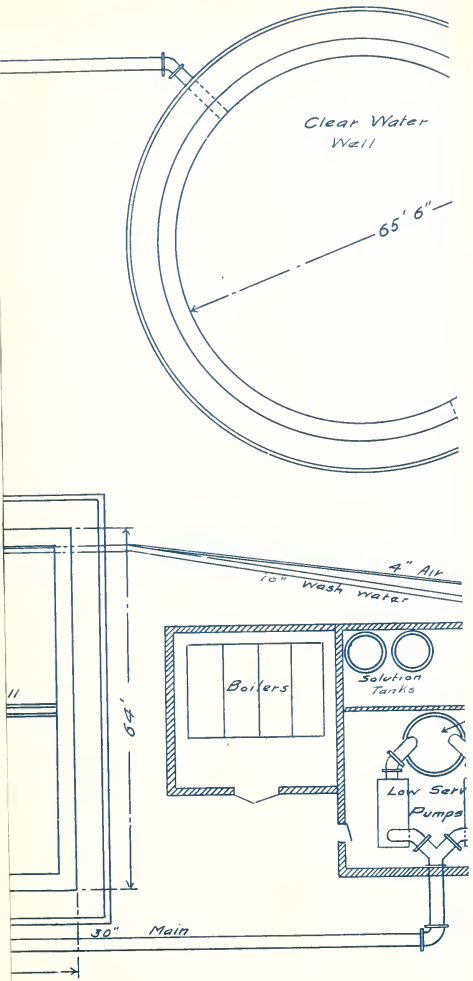
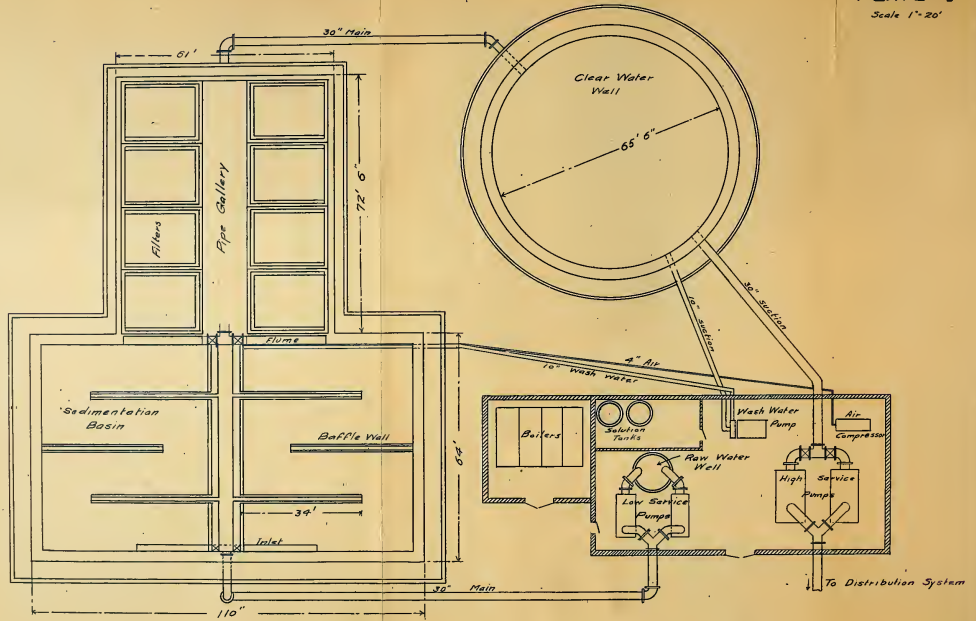


PLAN OF FILTER PL.

PLATE I

Scale 1"-20'



GENERAL PLAN OF FILTER PLANT

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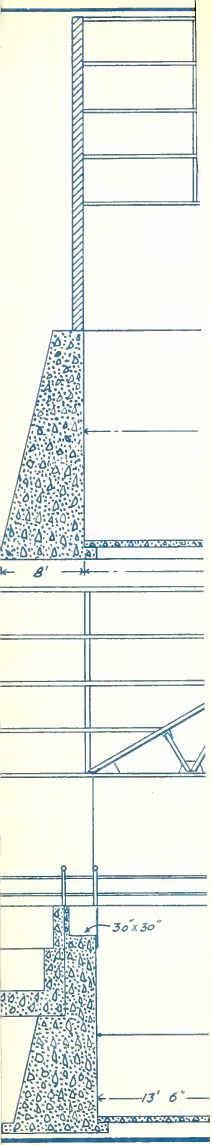
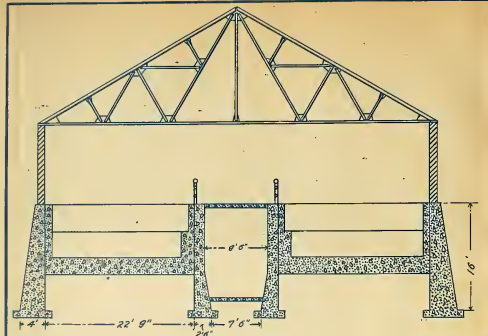
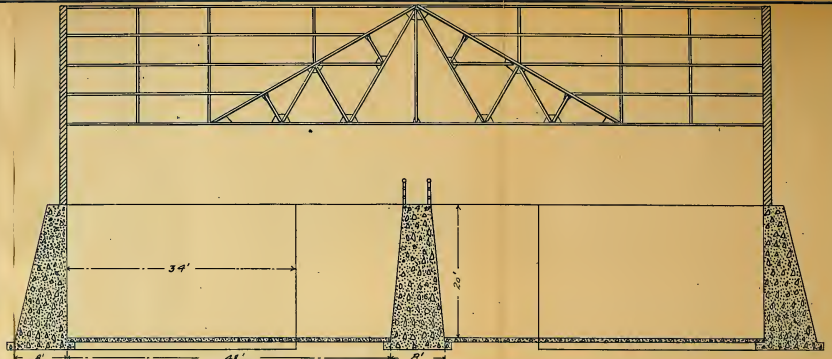
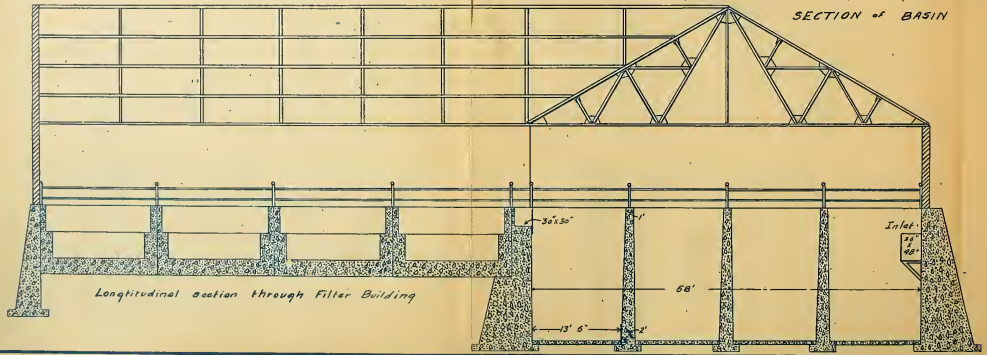

8'
30"x30"
13' 6"



SECTION of FILTER HOUSE



SECTION of BASIN



Longitudinal section through Filter Building

PLATE II

Scale 3/32" = 1'

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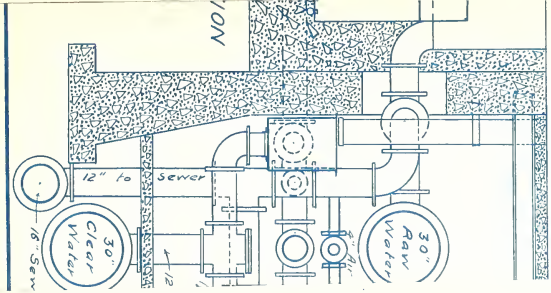
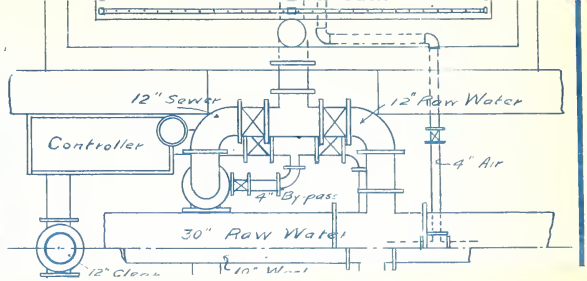
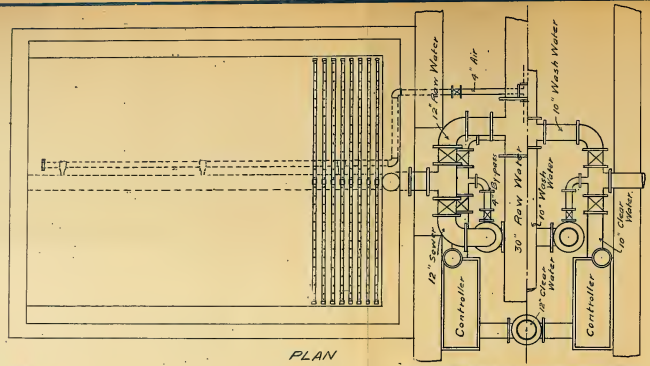
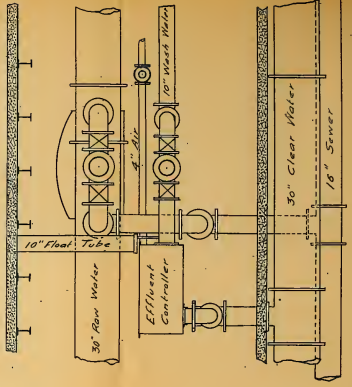
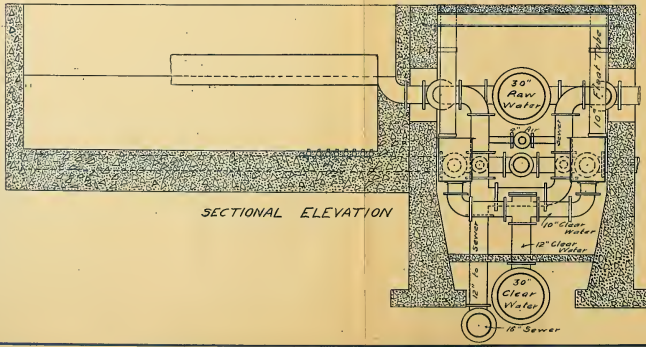

12" to sewer
30" Clear Water
30" Raw Water


12" Sewer
12" Raw Water
Controller
4" Air
4" By pas
30" Raw Water





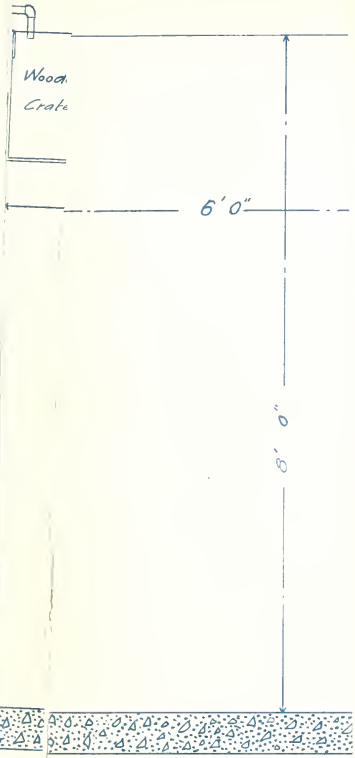


PLAN and SECTIONS of FILTER BED and PIPE GALLERY

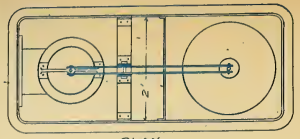
PLATE III

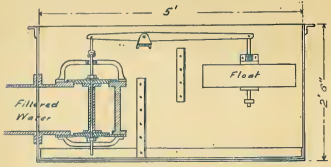
Scale ½" = 1'

Rec'd Sept 18 '14

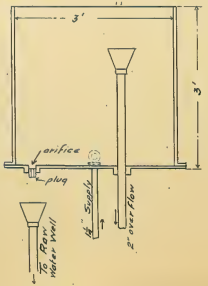


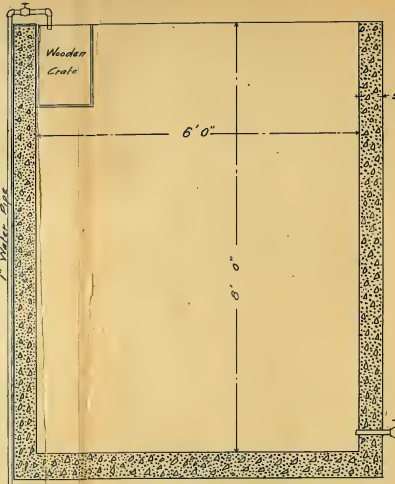
ELEVATION OF MIXING TA





ALUM SOLUTION MEASURING TANK





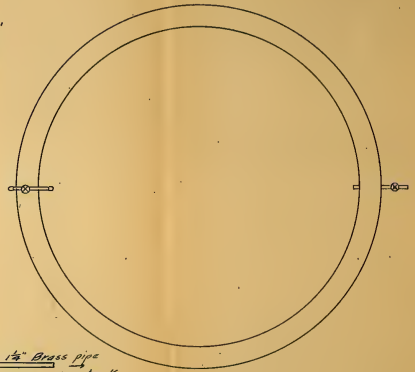


PLATE IV

Scale 3/4" = 1'

Roy S Spalding